

AN15044

MCX A344-based Inductive Encoder

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Application note

Document information

Information	Content
Keywords	MCX A344 device, Inductive Encoder, OPAMP, LPADC, MAU, FreeMASTER, AN15044
Abstract	This application note describes a reference implementation of an inductive encoder using the MCX A344 device. The demo acquires differential sine and cosine signals through the integrated OPAMP and LPADC peripherals. It calibrates the signal ellipse, calculates angle with MAU-assisted atan2, tracks multi-turn position, estimates speed, and visualizes the result with FreeMASTER.



1 Introduction

Inductive position encoders use coils and a conductive target to convert mechanical rotation into electrical sine and cosine signals. Compared with contact-based sensing, the inductive method supports sealed mechanics, tolerance to dust or oil, and board-level integration. The final accuracy depends on the sensor geometry, analog front end, calibration, mechanical alignment, and system-level validation.

The MCX A344-based inductive encoder demo shows how the MCU acquires the conditioned sine and cosine channels. It also shows how the MCU corrects typical amplitude and phase errors, calculates the angle at a deterministic rate, and exposes the result through FreeMASTER. The implementation is intentionally compact so that it can be reused as a reference for evaluation boards, motor-control fixtures, and industrial encoder experiments.

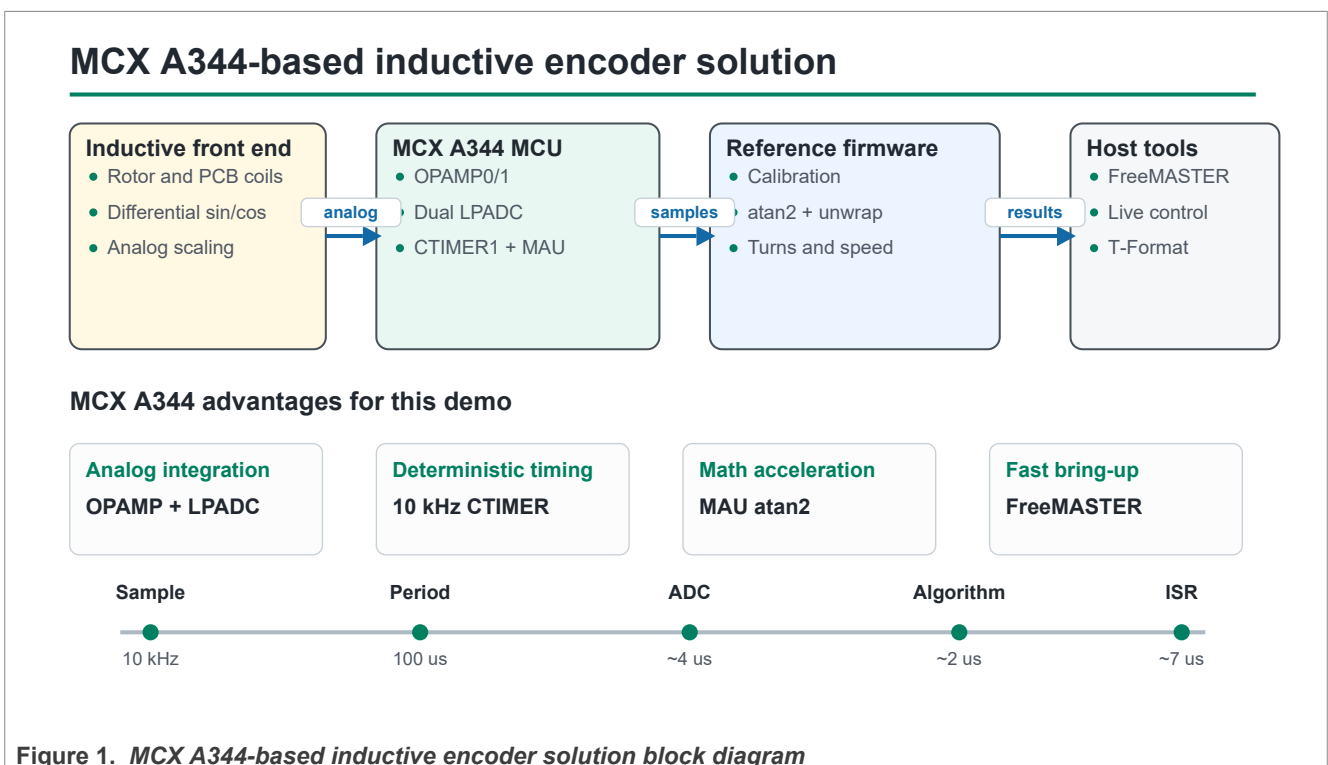


Figure 1. MCX A344-based inductive encoder solution block diagram

This application note is intended for firmware and hardware engineers who evaluate the MCX A344 device for inductive position sensing. It describes the reference demo as a starting point, not as a production accuracy claim.

2 Inductive encoder principles

A rotary inductive encoder typically includes an excitation structure, receiver coil patterns, and a rotor target. As the target rotates, the coupling between the excitation and receiver structures changes periodically. Receiver patterns that are shifted by 90 electrical degrees generate sine and cosine channels. A single mechanical revolution can contain multiple electrical cycles, depending on the coil and rotor geometry.

The reference firmware assumes two conditioned channels: sine and cosine. The channels are sampled as a pair, centered, transformed by a 2x2 calibration matrix, normalized by magnitude, and passed to atan2. The demo uses `ENCODER_ELEC_CYCLES_PER_REV = 4`, therefore, the electrical angle is converted to mechanical angle by dividing the unwrapped electrical angle by four.

This processing flow converts nonideal elliptical signal trajectories into a normalized circular representation, improving angle accuracy and robustness against amplitude and phase mismatches.

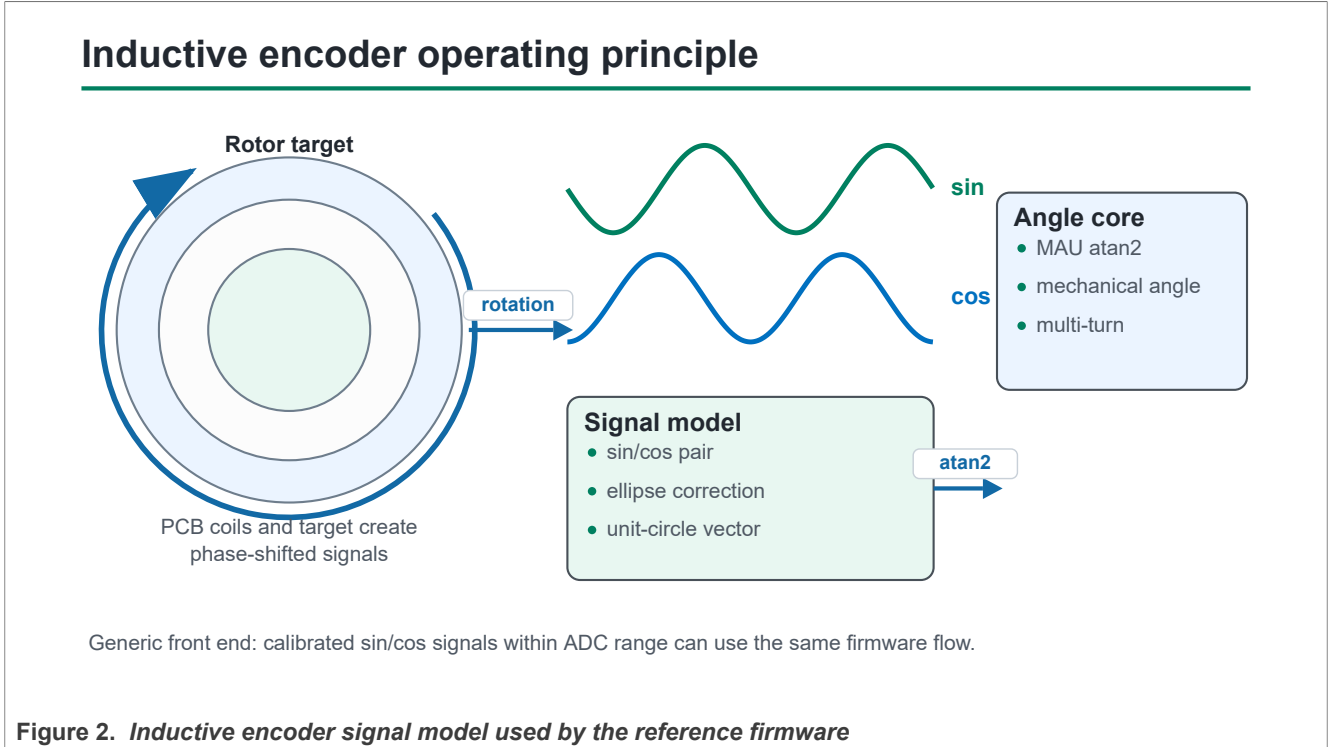


Figure 2. Inductive encoder signal model used by the reference firmware

Table 1. Encoder signal-processing concepts

Concept	Reference implementation
Differential sine/cosine inputs	The hardware provides differential OUT_SIN+/OUT_SIN- and OUT_COS+/OUT_COS-style channels. The firmware is generic and only requires ADC-range sine and cosine samples after analog conditioning.
Ellipse correction	Calibration estimates the sine/cosine channel centers and a 2x2 transform matrix, stored in <code>encoder_calibration_t</code> as <code>sin_center</code> , <code>cos_center</code> , and <code>transform[2][2]</code> .
Magnitude gate	A minimum magnitude threshold prevents angle updates when signal quality is too low. The reference constant is <code>ENCODER_MIN_MAG_THRESHOLD = 0.6f</code> .
Angle conversion	MAU-assisted <code>atan2</code> produces electrical angle. The result is unwrapped, divided by <code>ENCODER_ELEC_CYCLES_PER_REV</code> , and normalized to mechanical angle.
Multi-turn tracking	Electrical wrap detection updates an accumulated electrical angle and a mechanical turn counter.

3 MCX A344 device fit for the application

The MCX A344 device brings mixed-signal acquisition, deterministic timing, and accelerated math together in a single MCU for this application. The reference software uses the MCU peripherals as an integrated signal-processing pipeline rather than as independent blocks.

Table 2. Main MCU resources used by the reference demo

MCX A344 resource	Configuration in the demo	Application role
System clock	FROHF at 180 MHz through <code>BOARD_BootClockFROHF180M()</code> .	Provides CPU and peripheral timing margin for the 10 kHz sampling loop.

Table 2. Main MCU resources used by the reference demo...continued

MCX A344 resource	Configuration in the demo	Application role
OPAMP0 and OPAMP1	Configured during <code>Hardware_Init()</code> ; source uses OPAMP fit gain and bias configuration from the MCUXpresso driver.	Condition sine and cosine channels close to the MCU input path.
LPADC ADC0 and ADC1	Dual-channel acquisition of OPAMP outputs; ADC0_A2 and ADC1_A2 are used for the main signal path.	Sample sine and cosine data as input to <code>encoder_process()</code> .
CTIMER1	<code>sampler_init (SAMPLE_FRQ)</code> with <code>SAMPLE_FRQ = 10*1000</code> .	Generates the deterministic 10 kHz sampling interrupt.
MAU0	Initialized in <code>Hardware_Init()</code> ; <code>mau_atan2.c</code> wraps <code>MAU_AtanXDivPIFloat()</code> .	Accelerates atan2-style angle calculation in the encoder path.
LPUART0	Used by FreeMASTER and the debug console in the default application path.	Exposes real-time variables and control flags to the host dashboard.
LPUART2 and eDMA	Used only by the optional T-Format/Tamagawa demo.	Provides an experimental industrial encoder interface path, separate from the default Free MASTER demo.

4 Reference hardware summary

This application note does not include a schematic image in the main body. The hardware details described in this section are based on the *Inductive Encoder Reference Design (IND_ENC_v1r0)* document (see [Section 11](#)). The default software path remains generic: any front end that delivers conditioned sine and cosine signals within the MCU ADC range can reuse the firmware flow after calibration.

On the v1r0 reference board, a third-party inductive sensor front-end device generates differential OUT_SIN and OUT_COS signals. The schematic labels this device as AS5715R. This label is useful in understanding the reference board, however, the firmware is not tied to that device name.

Table 3. Reference hardware connections

Signal group	MCX A344 connection	Use in the demo
Sine input path	P2_12 and P2_13 feed OPAMP0 inputs; P2_15 is OPAMP0 output and ADC0_A2.	Condition and sample the sine channel.
Cosine input path	P2_16 and P2_17 feed OPAMP1 inputs; P2_19 is OPAMP1 output and ADC1_A2.	Condition and sample the cosine channel.
FreeMASTER UART	P2_0 and P2_1 are used for LPUART0 RX/TX.	Default host communication and live visualization.
Optional industrial UART	P2_2 and P2_3 are shown for LPUART2 TX/RX.	Used by the optional T-Format/Tamagawa experiment, not by the default demo path.
Clock and debug	The schematic includes reset, SWD, and an 8 MHz crystal circuit.	Board bring-up and debug support.

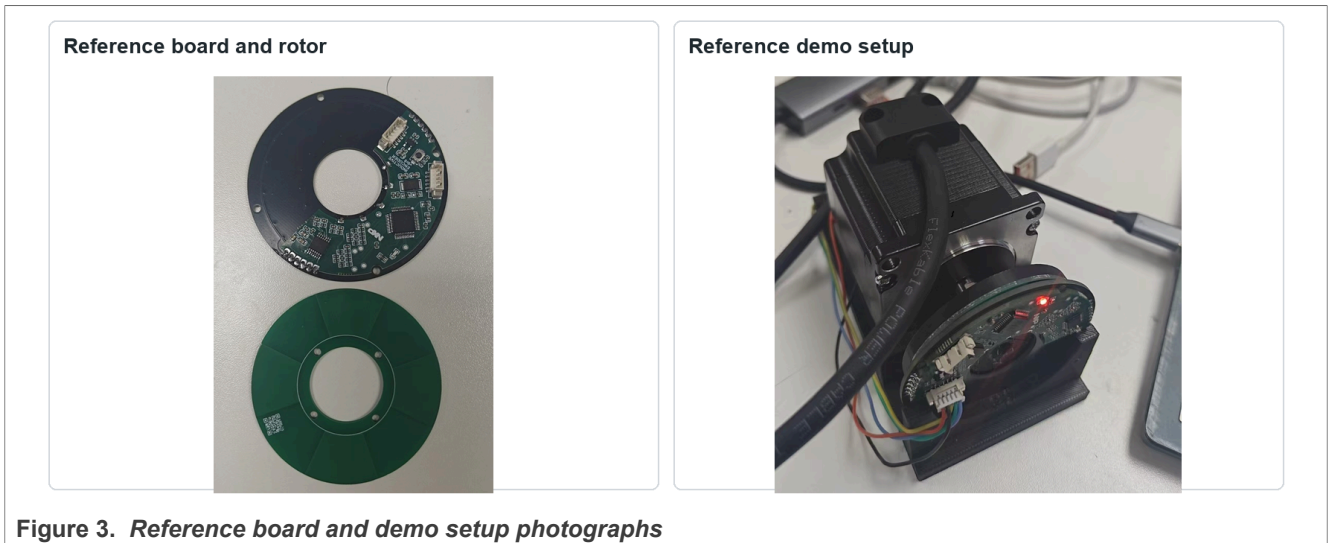


Figure 3. Reference board and demo setup photographs

5 Firmware framework and implementation

The firmware is organized around a small set of application modules. The `main.c` module initializes the board, starts the sampler, services FreeMASTER, and handles host commands. The `hardware_init.c` module configures clocks, pins, OPAMP, LPADC support, MAU, and utility GPIOs. The `app_sampler.c` module owns the CTIMER1 interrupt and calls `adc_read()` followed by `encoder_process()`. The `app_encoder.c` module contains calibration, normalization, angle, speed, zero, direction, and optional industrial-format helpers.

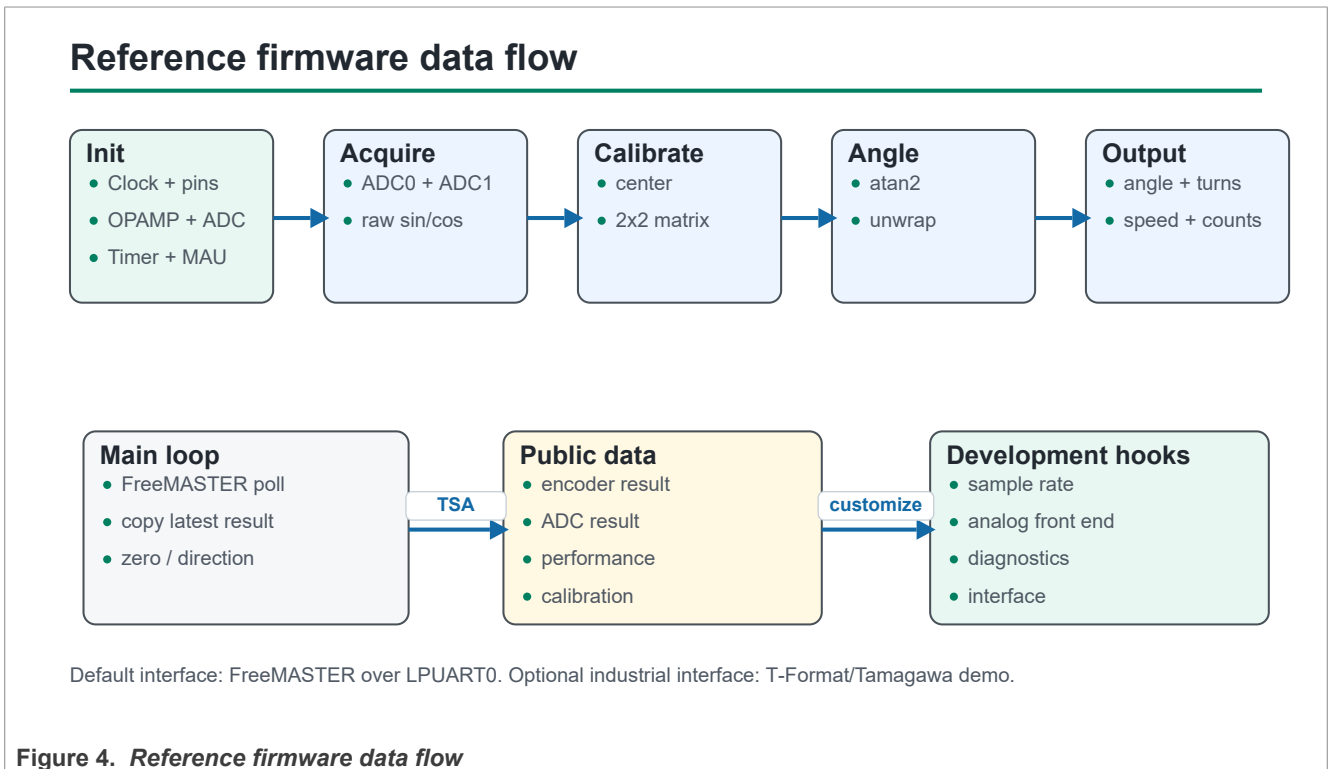


Figure 4. Reference firmware data flow

Table 4. Key source modules

Module	Main responsibility
source/main.c	Application entry point, SAMPLE_FRQ definition, FreeMASTER command handling, calibration, and zero-control orchestration.
source/hardware_init.c	MCX A344 clock, pin, OPAMP, MAU, console, and board utility initialization.
source/app_adc.c and source/app_adc.h	LPADC configuration and raw ADC acquisition for the encoder and temperature paths.
source/app_sampler.c and source/app_sampler.h	CTIMER1 sampling ISR and safe copy-out of the latest raw and processed results.
source/app_encoder.c and source/app_encoder.h	2x2 calibration, magnitude gate, atan2, unwrap, zero, direction, alpha-beta filtering, and encoder output data.
source/mau_atan2.c and source/mau_atan2.h	MAU-backed atan2 helper used by the encoder algorithm.
source/freemaster_example.c and source/freemaster_example.h	FreeMASTER TSA table, public variables, and host-accessible control flags.
source/app_tformat.c and source/app_tformat.h	Optional T-Format/Tamagawa response demo for ABS, ABM, ENID, SF, and ALMC fields.

5.1 Calibration and angle pipeline

The calibration routine collects raw sine and cosine samples while the rotor is moved through the required electrical range. It computes channel centers and an ellipse-to-circle transform, then stores the results in `s_calibration`. The runtime path subtracts the centers, applies the transform, computes the magnitude, normalizes the vector, and freezes angle updates when the magnitude is below the threshold.

The angle core uses the MAU-assisted atan2 helper. The electrical angle is unwrapped across 0/360° crossings, converted to mechanical angle using `ENCODER_ELEC_CYCLES_PER_REV = 4`. The firmware then applies zero and direction settings. An alpha-beta filter estimates speed while limiting spikes and enforcing a small deadband around zero speed.

Table 5. Public data and control variables

Symbol	Access	Purpose
<code>encoder_result_t / encoder_result</code>	Read only through FreeMASTER TSA	Raw channels, normalized channels, magnitude, electrical angle, mechanical angle, turns, angle counts, <code>speed_dps</code> , and <code>speed_rpm</code> .
<code>adc_sample_result_t / adc_result</code>	Read only through FreeMASTER TSA	Raw ADC-related values and temperature data used for observation and debug.
<code>perf_metrics_t / g_perf</code>	Read only through FreeMASTER TSA	Timing metrics: <code>adc_us</code> , <code>atan2_us</code> , <code>algo_us</code> , and <code>isr_us</code> .
<code>encoder_calibration_t / s_calibration</code>	Read only through FreeMASTER TSA	Calibration centers and 2x2 transform used by the angle path.
<code>fm_cal_enable</code>	Read/write through FreeMASTER TSA	Calibration starts from the host dashboard.
<code>fm_zero_ctrl</code>	Read/write through FreeMASTER TSA	Controls set-zero and clear-turns actions.
<code>fm_direction</code>	Read/write through FreeMASTER TSA	Selects the output direction sign.

5.2 Optional T-Format/Tamagawa interface

The optional industrial-interface code is not the default application path. It is provided as a demo for experimenting with T-Format/Tamagawa-style responses over LPUART2 and eDMA. The default bring-up and visualization path remain FreeMASTER over LPUART0.

Table 6. Optional T-Format data fields

Field	Meaning in the demo
ABS	Single-turn position counts derived from <code>encoder_result.angle_counts</code> .
ABM	Multi-turn counter with an application-side offset/tare helper.
ENID	Encoder ID byte, defaulted by the reference implementation.
SF	Status byte placeholder for future product diagnostics.
ALMC	Alarm byte placeholder for future product diagnostics.

6 FreeMASTER operation

FreeMASTER provides the default host interface. The dashboard reads raw ADC data, calibrated angle, speed, multi-turn count, calibration parameters, and performance counters. It also writes calibration, zero, clear-turns, and direction controls exposed through the TSA table.

FreeMASTER enables real-time interaction with the embedded application without requiring code modifications, making it a powerful tool for debugging, monitoring, and system tuning.

The communication between the MCU and FreeMASTER is handled through LPUART0, allowing continuous data streaming and control updates during runtime.

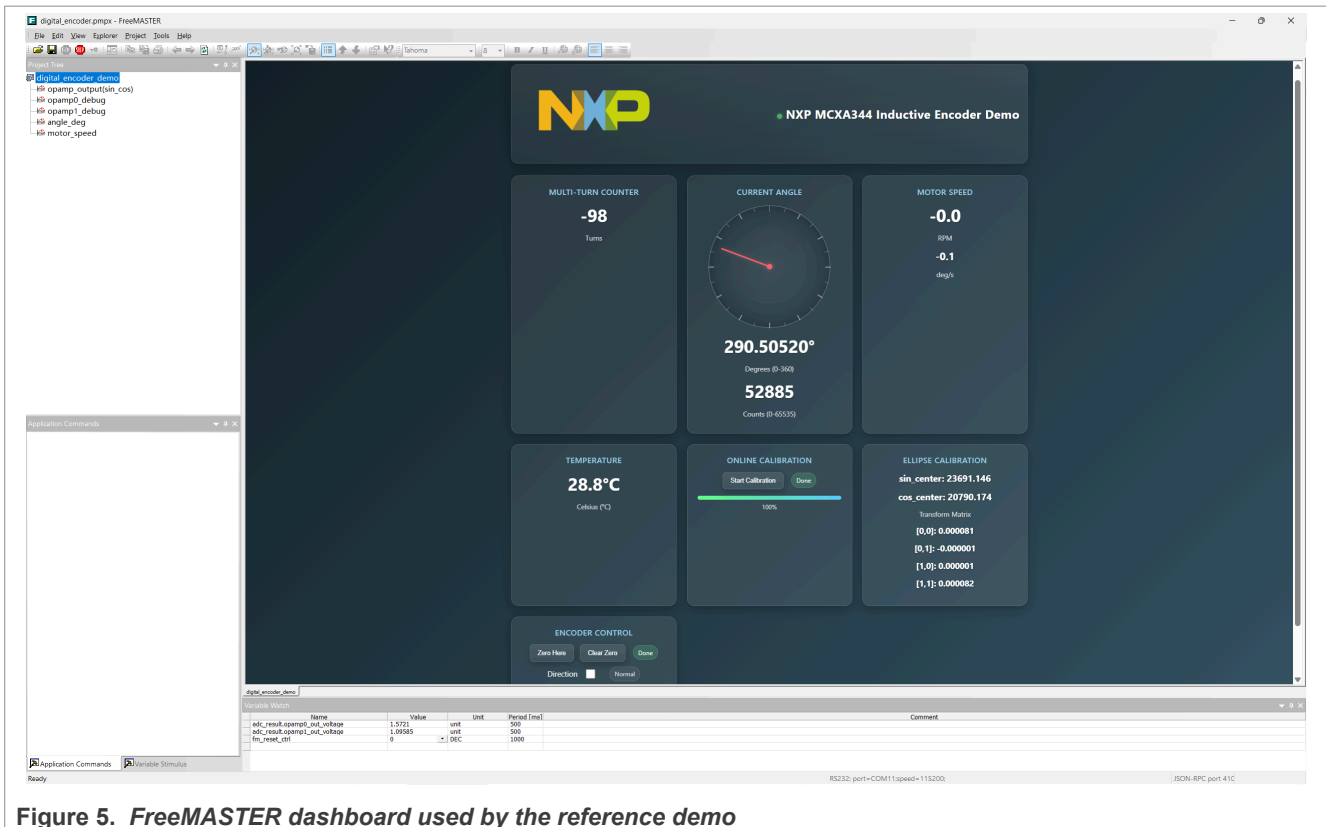


Figure 5. FreeMASTER dashboard used by the reference demo

Table 7. Typical FreeMASTER workflow

Step	Action	Expected observation
1	Connect the board to the host and open the FreeMASTER project or the web dashboard.	The dashboard starts showing raw ADC values, temperature, and encoder result variables.
2	Rotate the target and observe <code>sin_raw</code> , <code>cos_raw</code> , and <code>magnitude</code> .	Signals change smoothly and remain above the configured magnitude threshold for normal angle updates.
3	Run calibration while moving through the required electrical range.	<code>s_calibration</code> updates with centers and the 2x2 transform matrix.
4	Set zero and select direction as needed.	Values of <code>encoder_result.angle_deg</code> , <code>angle_counts</code> , <code>turns</code> , and <code>speed</code> follow the chosen output convention.
5	Watch <code>g_perf</code> timing metrics while changing sample rate or algorithm options.	<code>adc_us</code> , <code>atan2_us</code> , <code>algo_us</code> , and <code>isr_us</code> provide immediate timing feedback.

7 Performance summary

The reference firmware targets a 10 kHz update rate. `SAMPLE_FRQ` is defined as 10×1000 in `main.c`, and `ENCODER_SAMPLE_PERIOD_S` as $0.0001f$ in `app_encoder.h`. This definition gives a 100 μs period for acquisition and processing. The README reports typical timing values of approximately 4 μs for ADC access, 2 μs for the algorithm, and 7 μs for the full sampling ISR on the reference setup.

Table 8. Reference performance values

Item	Value	Source and note
Sampling/update rate	10 kHz	<code>SAMPLE_FRQ = 10*1000</code> in <code>source/main.c</code> .
Sampling period	100 μs	<code>ENCODER_SAMPLE_PERIOD_S = 0.0001f</code> in <code>source/app_encoder.h</code> .
Electrical cycles per revolution	4	<code>ENCODER_ELEC_CYCLES_PER_REV = 4</code> in <code>source/app_encoder.h</code> .
ADC acquisition time	~ 4 μs typical	README-reported <code>g_perf.adc_us</code> value for the reference demo.
Algorithm time	~ 2 μs typical	README-reported <code>g_perf.algo_us</code> value for normalization, angle, unwrap, filtering, and quantization.
Full sampling ISR time	~ 7 μs typical	README-reported <code>g_perf.isr_us</code> value including ADC and algorithm processing.

These values are reference-demo measurements and must be remeasured for the final board, clock configuration, compiler optimization level, and host interface. Accuracy, noise, latency, and temperature behavior require board-specific validation.

8 Getting started

The bring-up process ensures that both hardware and firmware are configured correctly before signal processing and calibration begin.

Table 9. Bring-up checklist

Step	Detail
Prepare hardware	Use the MCX A344 reference board and inductive encoder hardware. Verify power, ground, OPAMP inputs, ADC outputs, reset, SWD, and the FreeMASTER UART connection.
Open the firmware project	Open the Keil project <code>ind_encoder.uvprojx</code> and confirm that the MCX A344 device support and MCUXpresso SDK paths are available.
Build and flash	Build the <code>ind_encoder</code> target, flash the board, and verify that the debug console and heartbeat/test signals behave as expected.
Connect FreeMASTER	Open <code>freemaster/digital_encoder.pmpx</code> or the web dashboard and connect through the default LPUART0 path.
Check raw signals	Rotate the target and confirm that sine, cosine, and magnitude move smoothly before trusting the angle output.
Calibrate	Run calibration through <code>fm_cal_enable</code> . Use the resulting <code>s_calibration</code> values for the current hardware setup.
Set output convention	Use <code>fm_zero_ctrl</code> and <code>fm_direction</code> to set the mechanical zero and direction for the demo, respectively.

9 Secondary development guide

Use the reference demo as a starting point and keep the hardware-dependent assumptions explicitly defined. The most common productization tasks include calibration storage, diagnostics, sample rate tuning, signal-quality monitoring, interface integration, and validation under mechanical and temperature variations.

Table 10. Customization guide

Area	What to change	Validation focus
Sensor geometry	Update <code>ENCODER_ELEC_CYCLES_PER_REV</code> if the coil/rotor design has a different number of electrical cycles per mechanical revolution.	Mechanical angle scale wrap handling, and multi-turn count.
Sample rate	Change <code>SAMPLE_FRQ</code> and <code>ENCODER_SAMPLE_PERIOD_S</code> together, and review <code>CTIMER1</code> setup and filter tuning.	ISR margin, speed estimate stability, host update rate, and aliasing effects.
Analog front end	Adjust the OPAMP, LPADC, gain, bias, and pin configuration for the target board.	ADC input range, saturation margin, noise, phase shift, and magnitude threshold.
Calibration persistence	Store <code>encoder_calibration_t</code> in nonvolatile memory after production calibration.	Boot-time loading, versioning, invalid-data fallback, and recalibration handling.
Diagnostics	Map fault detection mechanisms to magnitude checks and optional <code>SF/ALMC</code> fields.	Fault coverage, recovery behavior, and host visibility.
Industrial interface	Enable or adapt the optional T-Format/Tamagawa interface only if the product requires it.	Timing, electrical transceiver, protocol compatibility, and isolation from the default FreeMASTER path.

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11 References

- [MCX A34 MCUs documentation](#) (webpage)
- [OPAMP Usage on MCX A3xx](#) (AN14682)
- [MCX A34x Triple-Motor Field-Oriented Control](#) (AN14805)
- [Migrating a Motor Control Application from TMS32F280013x to MCX A34x](#) (AN14866)
- [FreeMASTER Run-Time Debugging Tool](#) (webpage)
- *README.md, source/*.c, source/*.h, freemaster/*, and doc/IND_EC_v1r0/IND_ENC_v1r0.pdf (project files)*

12 Acronyms

Table 11. Acronyms

Acronym	Description
ABM	Multi-turn absolute position field used by the optional T-Format/Tamagawa demo
ABS	Single-turn absolute position field used by the optional T-Format/Tamagawa demo
ADC	Analog-to-digital converter
ALMC	Alarm code field used by the optional T-Format/Tamagawa demo
CTIMER	Counter/timer peripheral
ENID	Encoder ID field used by the optional T-Format/Tamagawa demo
ISR	Interrupt Service Routine
LPADC	Low-power analog-to-digital converter
MAU	Math accelerator unit
OPAMP	Operational amplifier peripheral
SF	Status field used by the optional T-Format/Tamagawa demo
SWD	Serial Wire Debug
TSA	Target-side address description used by FreeMASTER
UART	Universal Asynchronous Receiver/transmitter

13 Revision history

[Table 12](#) summarizes revisions to this document.

Table 12. Revision history

Document ID	Release date	Description
AN15044 v.1.0	27 May 2026	Initial public release

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